

Modeling and Validation of Transmission Range Adjustment Algorithm in Wireless Sensor Network Using Colored Petri Nets

Thesis submitted in partial fulfillment of the requirements for the degree of

Master of Technology

in

Computer Science and Engineering

(Specialization: Software Engineering)

by

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Rourkela, Odisha, 769008, India

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Certificate

This is to certify that the work in the thesis entitled "*Modeling and Validation of Transmission Range Adjustment Algorithm in Wireless Sensor Network Using Colored Petri Nets*" submitted by *Riju Arya* is a record of an original research work carried out by him under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Master of Technology in Computer Science and Engineering with the specialization of Computer Science in the department of Computer Science and Engineering, National Institute of Technology Rourkela. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

Place: NIT Rourkela
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Acknowledgment

I am grateful to numerous local and global peers who have contributed towards shaping this thesis. At the outset, I would like to express my sincere thanks to Prof. Suchismita Chinara for her advice during my thesis work. As my supervisor, she has constantly encouraged me to remain focused on achieving my goal. Her observations and comments helped me to establish the overall direction of the research and to move forward with investigation in depth. She has helped me greatly and been a source of knowledge.

I am very much indebted to Prof. Ashok Kumar Turuk, Head-CSE, for his continuous encouragement and support. He is always ready to help with a smile. I am also thankful to all the professors of the department for their support.

I am really thankful to my all friends and Research Scholars. My sincere thanks to everyone who has provided me with kind words, a welcome ear, new ideas, useful criticism, or their invaluable time, I am truly indebted.

I must acknowledge the academic resources that I have got from NIT Rourkela. I would like to thank administrative and technical staff members of the Department who have been kind enough to advise and help in their respective roles.

Last, but not the least, I would like to dedicate this thesis to my family, for their love, patience, and understanding.

Riju Arya

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Abstract

The interest, research and development in Wireless Sensor Network (WSN) is increasing day by day. In WSN the sensor nodes play the role of routers in broadcasting. One of the simplest way in broadcasting in WSN is flooding in which all the sensor nodes relay the data packets once with their full transmission range to attain the full network coverage. But as we know sensor nodes operate on limited battery power, resulting in wastage of power resources due to transmission at full power. So flooding proves itself to be an inefficient broadcasting technique. So there must be some other efficient techniques to solve the problem of minimum or lesser transmission energy broadcasting.

In the WSN nodes have capabilities of adjust their transmission range in a limit, as lesser transmission range leads us to more number of transmission but lesser power consumption at individual node. We try to cover both the aspects of WSN, that the nodes can be stationary or moving. We uses the concept of an optimal transmission radius, computed with a hexagonal tiling of the network area, that minimizes the total power consumption for a broadcasting task. We assume energy consumption for both the packet transmission and receptions.

In this thesis a Local Minimum Spanning Tree (LMST) algorithm is used to generate a LMST tree for the specified network area. In LMST we generate a fully connected graph containing all the sensor nodes with minimum sum of edge lengths. The idea behind using the minimum edge length(i.e. minimum transmission range) is that, $transmissionenergy \propto transmissionrange$.

For thesis purpose MATLAB is used to generate the LMST and to calculate the energy spent in broadcasting, and CPN is used to validate the LMST generated by MATLAB. CPN is a formal language's product which can validate the working of any algorithm or the protocol designed by any simulator.

Keywords: Transmission Range, Colored Petri Nets(CPN), Wireless Sensor Network(WSN).

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List of Abbreviations

CPN	Colored Petri Net
WSN	Wireless Sensor Networks
MST	Minimum Spanning Tree
LMST	Local Minimum Spanning Tree
QoS	Quality of Service

Chapter 1

Introduction

Wireless Sensor Network

Transmission Range Adjustment

Colored Petri Nets

Motivation and Objectives

Problem Definition

Thesis Organization

Chapter 1

Introduction

The nodes of Wireless Sensor Network(WSN) are autonomous sensor nodes which are distributed in a specified network area to monitor physical or environmental conditions. In order to transmit the data to other sensor nodes, nodes broadcast the collected data in the network and transfer finally to the sink. Nodes are equipped with wireless radio transceivers which enable them to move freely in reachable range of the network.

The nodes work on limited battery power resources, and have limited transmission range to be connected. So the necessity arises of minimum power consumption in broadcasting [20] the data and maintain the total connectivity of the network.

Such a scenario in WSN demands an efficient algorithm for broadcasting with energy efficient transmission along with optimal transmission range.

1.1 Wireless Sensor Network

The **WSN** is built of ‘nodes’, and the number of nodes may vary from one to few thousands, where each sensor node is connected to one (or multiple) sensors. Each wireless sensor node has several parts: a micro-controller, a radio transceiver, an electronic circuit for interfacing with the sensors and an energy source, usually a battery. A sensor node might be of varying size from a shoe-box to the size of a sand particle. In computer science, the WSNs are an active research area with several workshops and conferences each year. Application areas and Characteristics of WSN [15] are :

1.1.1 Application areas

Area Monitoring

Area monitoring is a highly common application area of WSNs. In this the WSN is deployed over a specified region where some condition is to be monitored. An army example in WSN is the use of sensors nodes detect enemy intrusion; another example is the temperature monitoring of furnaces in power-plants.

Environmental/Earth monitoring

“Environmental Sensor Networks”, is the term given to this area of WSN. It covers many applications of WSNs including sensing volcanoes, glaciers, oceans, forests, etc. Some of the major areas are listed below:

- Air quality monitoring
- Air pollution monitoring
- Forest fire detection
- Landslide detection
- Water quality monitoring
- Natural disaster prevention

Industrial monitoring

- Machine health monitoring
- Data logging
- Industrial sense and control applications
- Water/Waste water monitoring

Agriculture

Use of WSN in the agricultural industry is very common. WSN can free the farmer from maintaining wiring in a difficult environment. Water systems are monitored by pressure transmitters sensors to monitor level of water-tank, and pumps can be operated/controlled by wireless input output sensor devices and data can be transmitted to a central control wirelessly.

Smart home monitoring

Activities in a WSN monitored smart home are monitored by using wireless sensor nodes embedded in everyday objects which form a WSN. Human manipulations are captured based upon State changes to sensors of the wireless sensors network which enables activity-support services.

1.1.2 Characteristics

Energy consumption constraints for sensor nodes using batteries or energy harvesting

Energy harvesting is a process by which energy is captured and stored from the external source so that it can be used by sensor nodes in wireless sensor network. It refer to a limit on the maximum rate at which the energy can be used in WSN . This harvested energy availability typically varies with time in a non deterministic manner.

Ability to cope with node failures

Node Failure can occur in WSN as the nodes may run out of energy as a result of it communication can be permanently disturbed. To tolerate this failure redundant deployment of nodes is necessary.

Mobility of nodes

Mobility is provided by multi-hop network that does not require any fixed infrastructure, peer nodes take part in relaying information, Self-organizing and self-configuring It is useful as provides a fast network.

Communication failures

In case of wireless sensor network Communication means moving bits from one place to another but in case of WSN it means transferring actual information . In case of WSN the energy associated with nodes is limited so failure of any node can cause communication failure. In order to save this adapt new network interfaces etc.

Heterogeneity of nodes

In WSN ,the number of nodes per unit area i.e. the density of the network can vary considerably. Different applications will have different node densities .Even with in a network density may vary over time and space because nodes may fail or move.

Scalability to a large scale of deployment

Power of sensor nodes is limited and it is very costly procedure to deploy nodes again so the WSN must include large number of nodes and architecture and protocol used must be scalable to that number.

Ability to work in harsh environmental conditions

In order to process information correctly these nodes must be flexible on changes in their tasks. That is nodes must be programmable according to different environmental conditions.

Ease of use

In case of WSN it must be self configurable [16], self heal, self protect, self adapt so that it is ease to be used for real time applications like military, hospital etc.

1.2 Transmission Range Adjustment

The sensor node has to reliably deliver the information to other node(destination or relay node) with in the range called as transmission range of the node. We have to adjust this transmission energy in order to minimize the energy consumption

and for optimal power consumption. Following characteristics of transmission range :

1.2.1 Limits of Transmission Range

- Appropriate target distance, so that minimum energy consumption.
- Choice of transmission Power.
- Controlling the transmission power.

1.2.2 Purpose of Adjustment

We have to adjust the transmission range of nodes as the transmission power, that is the power radiated by antenna is major function of energy consumed during communication between two nodes. Moreover, this transmission power is function of system aspects like energy per bit over noise, the bandwidth efficiency, the distance and the path loss coefficient.

1.2.3 Effects on Power Consumption

The Energy consumption [17] of sensor nodes when transmitting a packet depends on transmitting range of transmitter u :

$$E(u) = \begin{cases} r(u)^a + c^e i f r(u) & \neq 0 \\ 0 & otherwise \end{cases} \quad (1.1)$$

$r(u)$ =transmitting range of u c^e =constant represents overhead due to signal processing This energy consumption must be minimum in order to increase the network lifetime of wireless sensor network.

1.2.4 Effects on WSN

The transmission range in case of WSN cannot be represented by fixed number ,it depends on the area in which the sensor has to be deployed. One important feature is the transmission power that must be minimum and position of antenna i.e. how this transmission power is distributed is important also. The network

lifetime and throughput can be improved by keeping short transmission range as it gives better frequency reuse and longer battery.

1.2.5 QoS

Two nodes can connect with each other only if they lie within their transmission range. Hence, in order to provide high Quality of Service i.e. multimedia service we must select appropriate transmission energy so that the quality of information extracted from nodes must be accurate and free from errors and delays.

1.3 Colored Petri Nets

CPNs provide a framework for the analysis and construction of concurrent and distributed systems. A CPN model can describe the states of the system and the transitions possible between them. The CPNs is better than traditional Petri Nets because, it supports **color**, **hierarchy**, and **time** in the models.

Hierarchy in CPNs enables the models to be structured into several co-related modules. This concept is taken from hierarchical structuring of the programming languages, which supports the top-down or bottom-up style. Created modules can be reused in various parts of the CPN models and again sub-modules can be derived from it. These modules in the CPNs are named as *pages*. In a complex model there maybe many number of pages varying from few to hundreds, same as a complex and lengthy program, which is sub-divided into number of modules. In the hierarchical CPNs, a transition with its associated components create a link to other CPNs providing more precise and accurate description of the activity interpreted by the transition. Such transitions are aroused the *substitution transitions*. The hierarchy caption in the *substitution transition* symbolize the details of substitution in detached modules called the *sub-pages*. All the places in a sub-page are marked with an input tag *Intag*, output tag *Outtag* or input/output tag *I/Otag*. These places are aroused the *port places*. They constitute the interface through which the sub page communicates with its surroundings.

Figure 5.2 represents a port place, where the place is assigned with *I/O-tag*.

The sub page receives tokens from its surroundings through the input port. It delivers tokens to its surroundings through the output ports and the *I/O* port communicates to its surroundings in both way. The places associated with a substitution transition are called the *socket places*. The port places of the sub pages are related to the *socket places* of the substitution transition by providing the port assignments. When a port place is assigned to a socket place, these places become identical. The socket place and the port place are two different views of one conceptual place, i.e. the port place and the socket place have always identical markings. When an input socket receives a token from the surroundings of the substitution transition, that token also becomes available at the input port of the sub-page, and hence the token can be used by the transitions on the sub-page. Similarly, the sub-page may produce tokens on an output port. Such tokens are also available at the corresponding output socket and hence they can be used by the surroundings of the substitution transition.

Another concept of hierarchical CPNs is the fusion places shown in figure 4.2. This indicates that a number of individual drawn places can be considered i.e they all represent a single conceptual place. When a token is added or removed at one of the places, an identical token will be added or removed at all other places in the fusion set. So it is clear that the relationship between the members of a fusion set is similar to the relationship between two places which are assigned to each other by a port assignment. When all members of a fusion set belong to a single page and that page has only one page instance, place fusion is nothing more than a drawing convenience to avoid too many crossing arcs in the model. But the situation is complex and interesting when the members of a fusion set belong to several different sub-pages or to a page that has several page instances. The various kinds of fusion sets are the global fusion sets, page fusion sets and instance fusion sets. The global fusion set can have members from different pages where as the page fusion set and instance fusion sets only have members from a single page.

Colors associated with each place in the CPNs determine the type of data

it may handle. The types of the places are similar to the types in programming language. It can be a complex type as the record which may contain heterogeneous data types. The color set is usually defined as:

colset No = int;

Where ‘colset’ is a keyword to declare the color set, ‘No’ is the name of the color set and ‘=int’ indicates that this colset can have integral values as tokens. The state of a CPNs is called as its state that shows the number of tokens distributed on the individual places. Each token carries a value that belongs to the type of the place on which the token resides. The tokens present on a particular place denotes the marking of that place. The initial state of a place is denoted as the initial marking of it. It is usually written in the upper left or right of the place as shown in Figure 5.2 and Figure 5.3.

Time concept into the CPNs is redefined as timed CPNs. This introduces the concept of global clock. The clock value which is either discrete or continuous represent the model time. In the timed CPNs, each token carries a time value called the time stamp. The time stamp describes the earliest model time at which the token can be used, that is it can be removed by the occurrence of a binding element. In a timed CPNs a binding element is said to be color enabled when it satisfies the enabling rule for un-timed CPNs. However, to be enabled, the time stamps of the tokens to be removed must be less than or equal to the current model time.

The marking of a place where the tokens are carrying a time stamp becomes a timed multi-set specifying the elements with their number of occurrences and their time stamps. The timed color sets are declared as :

colset No = int timed;

and the marking of a place with timed token is as:

2'1@[9,15]

This indicates the marking contains two tokens with value 1 and time stamps 9 and 15 respectively. The @ symbol can be read as ‘at’ and the symbol [] is used to specify the time stamps.

1.4 Motivation

Research on wireless sensor networks begin in 1980 with the Distributed Sensor Networks (DSN) program at DARPA (Defense Advanced Research Projects Agency) where Arpanet (predecessor of the Internet) approach for communication was further extended to sensor networks. The network was having assumption of many spatially decentralized low-cost sensor nodes that collaborate with each other but operate autonomously, with data being usually broadcast. Sensor network included sensors, communication, processing techniques and algorithms and decentralized operating software. Distributed sensor tracking was chosen as the target problem for demonstration.

This limitation of power consumption caused the researchers to find a solution for optimal radius utilization in devices exchanging minimum number of messages.

In wireless broadcasting energy efficient transmission is very challenging task. Due to dynamic nature of the network topology, computation of optimal transmission range is a very challenging problem, there by providing less energy efficiency. Transmission energy control is the wise selection of lowest power consumption technique in WSN by which the network remains connected. The energy efficient routes for a sender receiver pair are computed with optimal transmission ranges on each node and the level with lowest energy consumption is selected for this transmission for that particular transmission. In case of multiple nodes, energy efficient route for each transmission is calculated. The importance of optimal transmission range arises from the fact that it has a major impact on the battery life of the whole network. So if a energy efficient path with optimal transmission range is feasible on each transmission, then we can optimize our result by sending packets through a more efficient path. The proposed work is motivated by the previous broadcasting algorithms to make the network energy efficient because the main resource constraint of the node is energy.

1.5 Problem Definition

This thesis work focuses on broadcasting problem in wireless sensor network, which seeks to find a local minimum spanning tree of the sensor nodes in the network with the use of a concept of optimal transmission range. Which seeks to maximize energy efficient broadcasting in WSN and maximum lifetime of the network ensuring total coverage of the network.

The problem is quantified and addressed by using MATLAB and CPN mathematical tools and an existing algorithm is used to model. The central objective is to find a better solution than the existing one for optimal transmission range in broadcasting in WSN.

1.6 Thesis Organization

The rest of the thesis is organized as follows: In Chapter 2, a literature survey is done on various algorithms in area of broadcasting in WSN, and their validation using colored petri nets. In Chapter 3, necessity and computation of optimal transmission range is done. In Chapter 4, modeling and simulation of LMST algorithm with Optimal Transmission Range is done using MATLAB. In Chapter 5, validation of LMST is done in various stages using hierarchical colored petri nets. Finally in Chapter 6, conclusions, scope for the future work and also the limitations is discussed.

Chapter 2

Literature Survey

Chapter 2

Literature Survey

As explained by Kurt Jensen, colored petri nets simulated and validated the sender and receiver protocol which represented the working of CPN in the area of networking [1]. Colored Petri Nets have been used by some of the researchers for validating and modeling some of the features of the mobile wireless sensor networks. Chinara et. al. [2] have proposed the validation of neighbor detection protocol for ad-hoc network by using the CPN tools.

Ali Shareef et. al. [3] , explained how energy modelling of wireless sensor network is done using markov model using petri nets. Bruno Lacerda et. al. [4], described the data flow of wireless sensor networks using colored petri nets, and simulated one node to multi hop data flow which is able to lead us to solution of the minimum energy broadcasting problem. Supriya Agrahari et.al. [5] illustrated the working of hierarchical petri nets in simulation of wireless network, which helped in understanding the modularization of any networking problem using the petri nets. Julien Cartigny, et. al. [6] applied the use of broadcasting algorithms like LMST and Relay Node Graph(RNG), in energy efficient broadcasting in wireless sensor network. In which nodes only observe the behavior and positions of their neighborhood only. Francois Ingelrest et. al. [7] compared the global protocols and local protocols and showed how can localized algorithms be better in wireless sensor networks, and how optimal transmission range is computed by hexagonal tiling of the network area.

It has been noticed that significant amount work hasn't been done in the area of wireless sensor networks by using petri net tools. Which provides ample

motivation for this thesis work where CPN tool has been used for the modeling and validation of energy efficient broadcasting in wireless sensor network.

Chapter 3

Computation of Optimal Transmission Range

Preliminaries

Reducing the Number of Transmissions

Adjusting Radii

The Computation of an Optimal transmission Range

Conclusion

Chapter 3

Computation of Optimal Transmission Range

3.1 Preliminaries

We represent the Wireless Sensor Network by a graph $W=(S,E)$, where S is the set of sensor nodes and $E \subseteq S^2$ is set of edges which provides the available communications : (x,y) belongs to E means that x is a neighbor of y , i.e., x can directly(physically) connect to y . Let us take an assumption that the maximum range upto a node can transmit is R , is same for all sensor nodes and that $d(u,v)$ is the Euclidean distance between u and v . The set E is then defined as follows:

$$E = \{(u, v) \in V^2 | d(u, v) \leq R\}$$

The proposed graph is called a unit graph, with R as its maximum transmission range. Example of a unit graph is given in Figure-3.1. Each node $x \in S$ is allocated a unique identifier (id), so that this identifier of x is denoted by $id(x)$. Then we also define node or vertex x neighborhood set $N(x)$ as: $N(x) = \{y | (x, y) \in E\}$. The size of this set, $|N(x)|$, is known as degree of x . The average degree of each node is called density of the graph. Note that (x,x) is not in E .

Nodes in a minimum wireless sensor network need position information of their neighbors. The common way to gain this information is the use of special messages(Ex: HELLO messages) that are periodically send by each node, carrying their own position. To find their own position, nodes use GPS.

We assume all packets are of same size(number of bits). Most commonly used

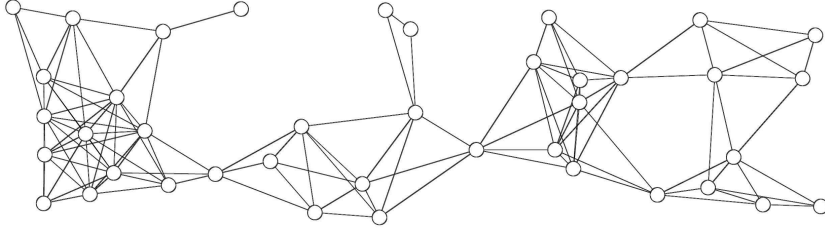


Figure 3.1: Example of a unit graph

transmission energy model measures the energy consumption of wireless network nodes when transmitting a prefixed size message on the basis of the transmission range of the transmitter x :

$$E(x) = \begin{cases} r(x)^\alpha + c_e & \text{if } r(x) \neq 0 \\ 0 & \text{otherwise.} \end{cases}$$

$r(x)$ being the transmitting range of u and c_e a constant that represents an overhead due signal processing. The model $\alpha = 4, c_e = 10^6 \text{units}$ is derived from a work by Rodoplu and Meng [14], and it is sufficiently realistic to be a reference. These expressed values are in generalized units, and could convert into desired units by the corresponding multiplication factor. Sensor also consume energy upon the packet reception. This consumption c_r is constant, independent of the distance between the sender and the receiver. The value generally used for c_r is one third of a 100-meter emission energy, that is, $c_r = \frac{1}{3} \times 100^\alpha + c_e$). In the previously stated model, this gives $c_r = \frac{2}{3} \times 10^6 \text{units}$.

A simple protocol to broadcast a message is Blind Flooding: Each sensor node simply relays the message to its neighborhood once. Many algorithms have been proposed to overcome this inefficient method,two main solutions are:

- Minimize the number of transmission to obtain a total coverage.
- Radius adjustment to further minimize energy consumption. Nodes can vary in interval of zero and the maximum transmission range value.

These solutions assume antennas to be omni-directional, that is a node transmission is received by all the neighbors located in the selected transmission range.

3.2 Reducing the Number of Transmissions

A protocol belongs to this family named as MPR (Multipoint Relay Protocol) [8] has been proposed by Qayyum et al. It follows greedy heuristics which enables nodes selecting their own relays just before re-transmitting. The above selection, which is forwarding the broadcasting packet, is made by an optimal subset of direct physical neighbors which totally covers the two-hop neighborhood. Nodes which receive this data packet, but are not selected for forwarding, do not transmit it. The above protocol is used in IETF standardized routing protocol called as OLSR (Optimized Link State Routing) [9].

The Neighbor Elimination Scheme(NES) [10] was solely proposed. In this, nodes relay the messages after monitoring their physical neighbors for a given span of time. Neighbors that have received a copy of exactly same message are removed from a uncovered neighbors list. If this uncovered list becomes vacant before the timeout, the re-transmission is canceled.

3.3 Adjusting Radii

Several broadcasting protocols are there for adjusting transmission radius work on the basis of the computation of a connected sub-graph of the original sensor network graph G . Length of the edges of the considered sub-graph are used to calculate communication radius. The following three sub-graphs are used:

- The Minimum Spanning Tree(MST) [11] is a tree connecting all nodes whose total edge weight is minimum. The weight is used to be the edge length, this tree has edges one less than the number of nodes in graph.
- The Relative Neighborhood Graph(RNG) [12], which eliminates the longest edge in any triangle of the graph and it has an average degree of 2.6.

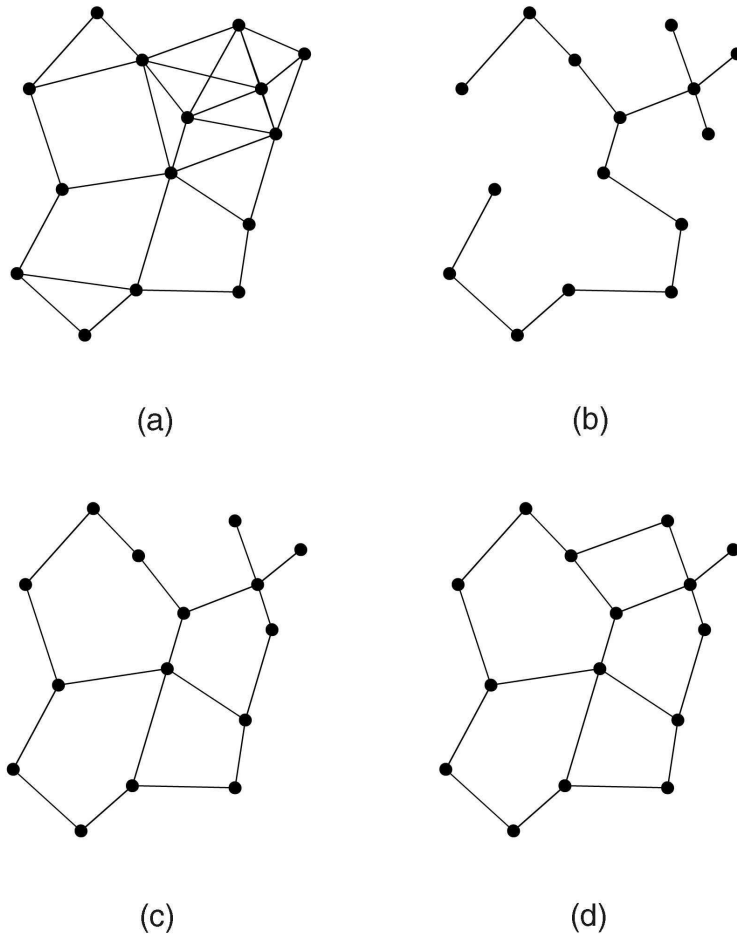


Figure 3.2: Example of sub-graphs. (a) Unit graph. (b) MST. (c) LMST. (d) RNG.

- The Local Minimum Spanning Tree(LMST) [6], in which nodes compute the MST of their physical neighbors within a given transmission range and keep only edges chosen by both endpoints inside their respective MSTs. LMST has 2.04 average degree [13] and has been proven to be a sub-graph of the RNG [18] . It is proven that MST is a subset of LMST [19].

Figure-3.2 shows these sub-graphs. Only the MST requires global knowledge of the network i.e. is a centralized protocol, and information of the whole topology is required for the computation of it. The Relative graph RNG can be computed locally without requirement of any exchange of messages. In the computation of Localized graph LMST one message from each node is required in order to eliminate asymmetric node links. LMST offers good performance (except in highly dense networks), but is costly to implement because of partial centralized computation of MST.

3.4 The Computation of an Optimal transmission Range

We consider a rectangular area A(200*200 sq. units) on which some sensor nodes are to be distributed. These nodes will broadcast the data so have to perform flooding, to cover the whole area. Transmissions are done within a range that is to be optimized in this work, our goal is to perform the task while minimum energy spent. So two related parameters are to be set:

- The number of nodes, denoted by n .
- The range used for emissions, denoted by r .

We choose a hexagonal tiling i.e., the area is segmented into many hexagons, and nodes are placed on vertices of it. The distance between emitters and receiver should be exactly r to avoid holes and ‘useless’ nodes in network area. So we fixed r as the side length of the hexagon. To cover the area A the number of vertices n (i.e., nodes) depends on the value of r , as showed by Figure-3.3

We can simply calculate the needed number of nodes for covering the whole area

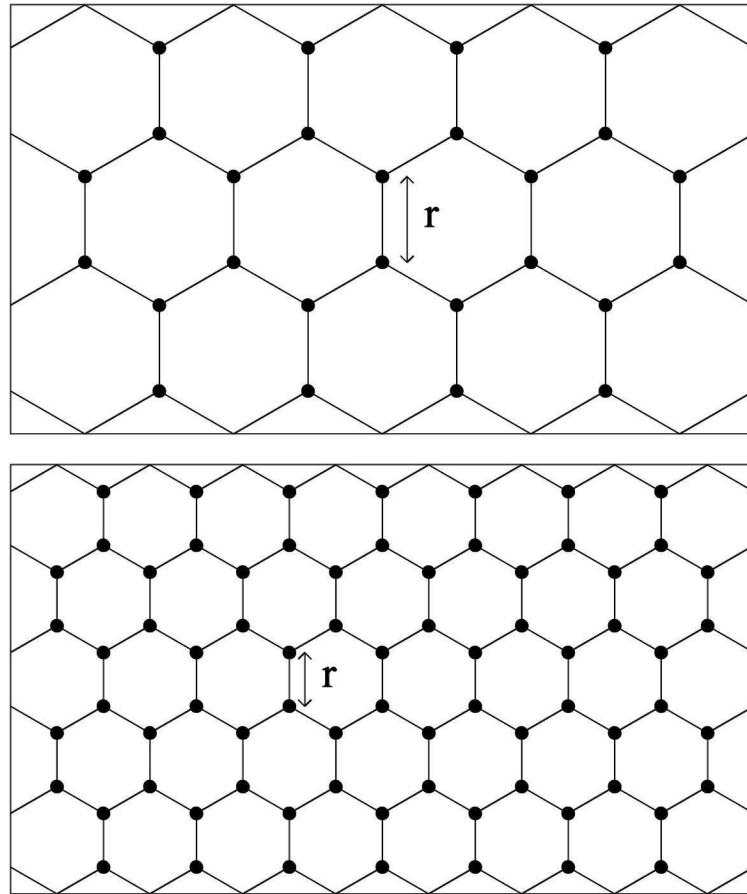


Figure 3.3: Hexagonal tiling of the area $A(200*200 \text{ sq. units})$ for different values of r .

A. So we only have to compute number of hexagons (h), fit in area of surface A:

$$h = \frac{\text{Area of Region}}{\text{Area of Hexagon}} = \frac{A}{\frac{3}{2}r^2\sqrt{3}} = \frac{2A}{3r^2\sqrt{3}}$$

To tile the required area, two nodes per hexagon have to be placed (because each hexagon has six nodes, and each node is shared by three hexagons), then the number of nodes n are:

$$n = 2h = \frac{k}{r^2}, k = \frac{4A}{3\sqrt{3}}$$

k is a constant independent of r.

In practical scenario, nodes have to spent some energy while receiving messages. And each transmission will reached to a number of neighbors depending upon the area covered by the transmission, which depends on the radius r. If d is original density with the maximum range R (we assume 200 units), then the density d(r) with radius r will be:

$$d(r) = d \times \frac{\text{Area covered with radius } r}{\text{Area covered with radius } R} = d \times \frac{\pi r^2}{\pi R^2} = d \times \frac{r^2}{R^2}$$

Thus, a node transmitting with radius r reaches d(r) neighbors. Let us consider the transmitting nodes do not switch off their receiver and, so we charge a reception to the transmitter. The energy consumption of the broadcasting becomes:

$$PC(r) = \underbrace{n \times (r^\alpha + c_e)}_{\text{Emissions}} + \underbrace{n \times c_r \times (d(r) + 1)}_{\text{Receptions}},$$

Which becomes:

$$PC(r) = k \times \left(r^{\alpha-2} + (c_e + c_r)r^{-2} + \frac{dc_r}{R^2} \right)$$

Considering the case when $\alpha > 2$, $c_e \neq 0$, and $dc_r \neq 0$, the derivative of this function is:

$$PC'(r) = k((\alpha - 2)r^{\alpha-3} - 2(c_e + c_r)r^{-3}),$$

Which reaches zero when

$$r = \sqrt[\alpha]{\frac{2(c_e + c_r)}{\alpha - 2}}$$

Figure-3.4 shows the energy consumption of the flooding when the model of Rodoplu and Meng [14] is considered ($\alpha = 4$, $c_e = 10^6 \text{ units}$, and $dc_r = \frac{2}{3} \times 10^6 \text{ units}$. and we consider $R = 200 \text{ units}$, $A = 40000 \text{ sq. units}$.

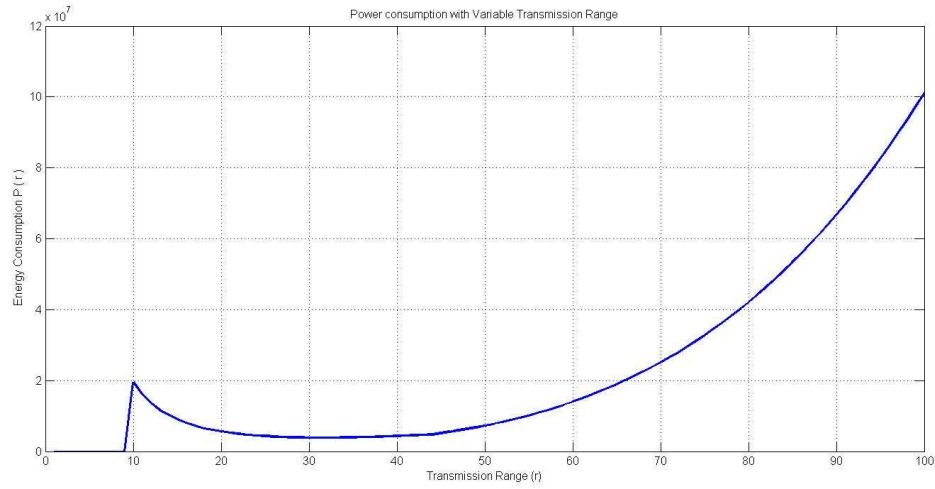


Figure 3.4: Power consumption with variable transmission range

There is a minimum value of the energy consumption, which happens with $r = 36$.

If the transmitting nodes switch off their receiver to avoid energy use for the unwanted reception, the “+1” part of the total energy consumption equation $PC(r)$ will be eliminated, and the equation for the transmission range becomes the same with a special case $c_r = 0$).

3.5 Conclusion

Many broadcasting protocols are proposed recently, having the goal of minimizing the transmission energy consumption, with the guarantee of total coverage of the wireless network. But, they were based on the techniques which requires global knowledge of the whole network and without optimal selection of the transmission range. So they did not performed For dense networks, it resulted in energy inefficient solutions. In this chapter we presents the optimal transmission range, computed by a hexagonal tiling of the area of network. Nodes may or may not sleep after transmitting the data packet.

Chapter 4

Simulation of LMST algorithm with Optimal Transmission Range using MATLAB

Implementation

Conclusion

Chapter 4

Simulation of LMST algorithm with Optimal Transmission Range using MATLAB

4.1 Implementation

To implement any wireless sensor network algorithm, selection of a network area and distribution of sensor nodes in that is necessary. As we know there is now fixed topology in WSN so we chose random distribution of the sensor nodes. In figure-3.4, it can be clearly observed, that the function $P(r)$ has low slope near the optimal range, So deflection of up to 20% from the optimal range does not have much impact on the optimality. So we chose a transmission range of $36 - 20\% = 28.8unit$ to calculate the number of nodes to be used to acquire the full network area according to hexagonal tiling formula $n = 2h = \frac{4A}{r^2 * 3\sqrt{3}}$.

Which results the number of nodes to be 38, so we take around 50 nodes to not to lose the connectivity, because of the randomness in the nodes distribution.

Now we generate a connected network graph of 50 nodes in area of $200 * 200$ sq. units with an optimal range of $36 + 20\% = 43.2$ units. shown in Figure-4.1

Then we generate its MST using kruskal's modified algorithm in MATLAB to find an energy efficient broadcasting solution. which is shown in Figure-4.2.

Further we take our generated MST to expand it upto LMST, which is done by connecting those nodes which lies mutually in transmission range of each other generated by MST. This approach leads us to the fast broadcasting in WSN, and

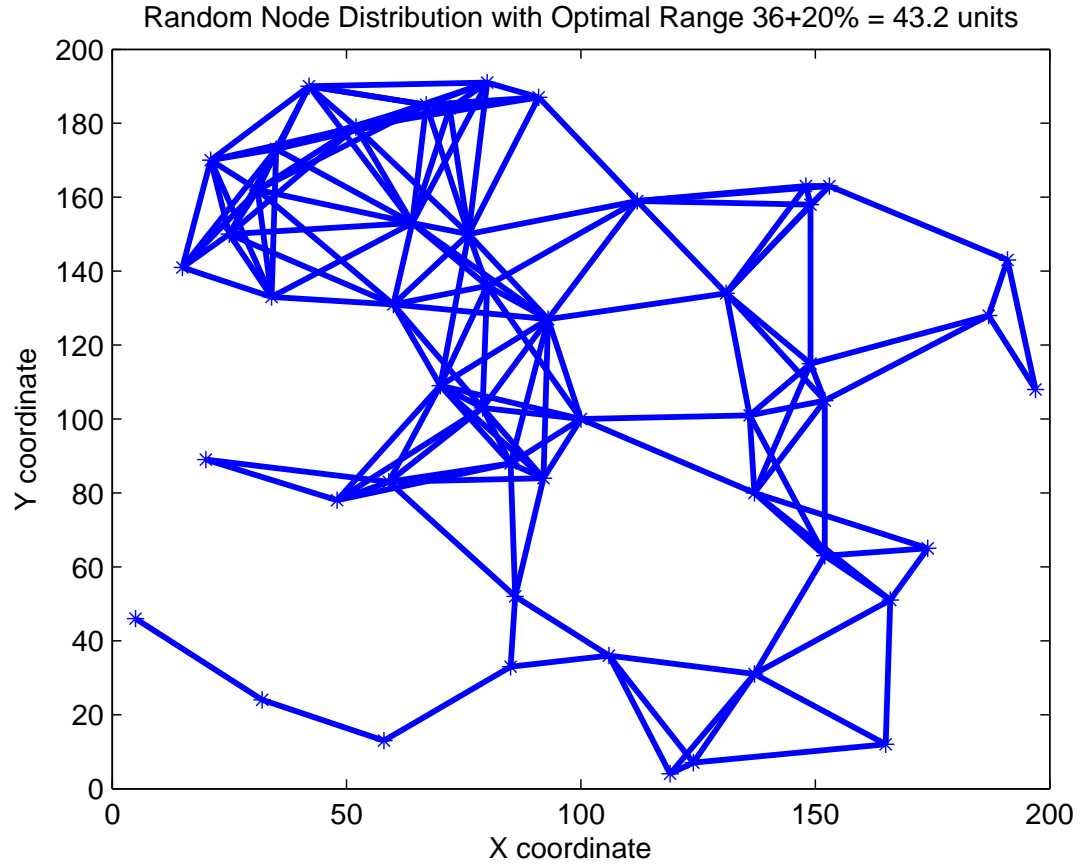


Figure 4.1: Random Node Distribution

Algorithm 1 LMST

```

 $N \leftarrow \text{number of nodes}, \text{RANGE} \leftarrow 43.2$ 
 $LINES \leftarrow 1$ 
for  $I \leftarrow 1$  to  $N$  do
  for  $J \leftarrow I+1$  TO  $N$  do
    if  $\text{distance}(\text{NODE}(I), \text{NODE}(J)) \leq \text{RANGE}$  then
       $\text{CONNECTION}(LINES) = (I, J, \text{distance}(\text{NODE}(I), \text{NODE}(J)))$ 
       $LINES \leftarrow LINES + 1$ 
       $\text{CONNECTION}(LINES) = (J, I, \text{distance}(\text{NODE}(I), \text{NODE}(J)))$ 
       $LINES \leftarrow LINES + 1$ 
    end if
  end for
end for
 $\text{CALLMST}(\text{CONNECTION}, N)$ 
 $\text{CALLADD\_EDGES}(\text{MST}, \text{RANGE})$ 
return LMST

```

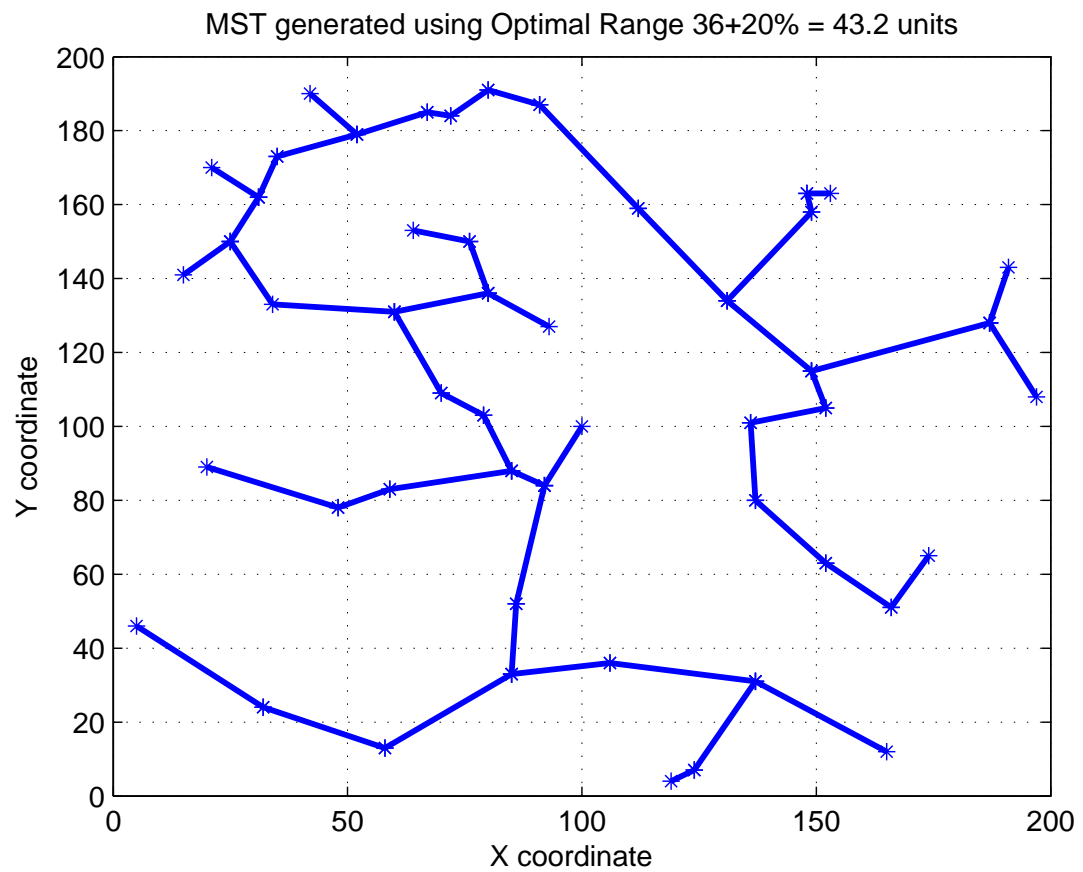


Figure 4.2: MST

Algorithm 2 MST

```

 $M \leftarrow \text{numberofrows}(\text{CONNECTION}), \text{VISITED} \leftarrow \{1\}$ 
 $\text{EDGES} \leftarrow 0$ 
for  $I \leftarrow 1$  to  $N$  do
   $\text{RANGE}(I) \leftarrow 0$ 
end for
while  $\text{EDGES} < N$  do
  Select minimum edge length  $(R,S,D)$  from CONNECTION, Where  $R \in \text{VISITED}$ 
   $\text{MST}(\text{EDGES}) \leftarrow (R, S, D)$ 
  CONNECTION = CONNECTION -  $(R,S,D)$ 
  CONNECTION = CONNECTION -  $(S,R,D)$ 
  VISITED = VISITED  $\cup \{S\}$ 
   $\text{EDGES} \leftarrow \text{EDGES} + 1$ 
  if  $\text{RANGE}(R) < D$  then
     $\text{RANGE}(R) = D$ 
  end if
  if  $\text{RANGE}(S) < D$  then
     $\text{RANGE}(S) = D$ 
  end if
end while

```

much efficient for dense network.

Algorithm 3 ADD_ EDGES

```

 $\text{LMST} \leftarrow \text{MST}, \text{EDGES} \leftarrow N - 1$ 
for  $I \leftarrow 1$  to  $N$  do
  for  $J \leftarrow 1$  to  $N$  do
    if  $\text{distance}(\text{NODE}(I), \text{NODE}(J)) \leq \text{RANGE}(I)$  then
      if  $\text{distance}(\text{NODE}(I), \text{NODE}(J)) \leq \text{RANGE}(J)$  then
         $\text{LMST}(\text{EDGES}) = (I, J, \text{distance}(\text{NODE}(I), \text{NODE}(J)))$ 
      end if
    end if
  end for
end for
return LMST

```

4.2 Conclusion

We will further validate above LMST in next chapter using CPN. For this validation we will take the coordinates of the randomly distributed nodes in a text file which will be the input for CPN, providing the tokens for the validation.

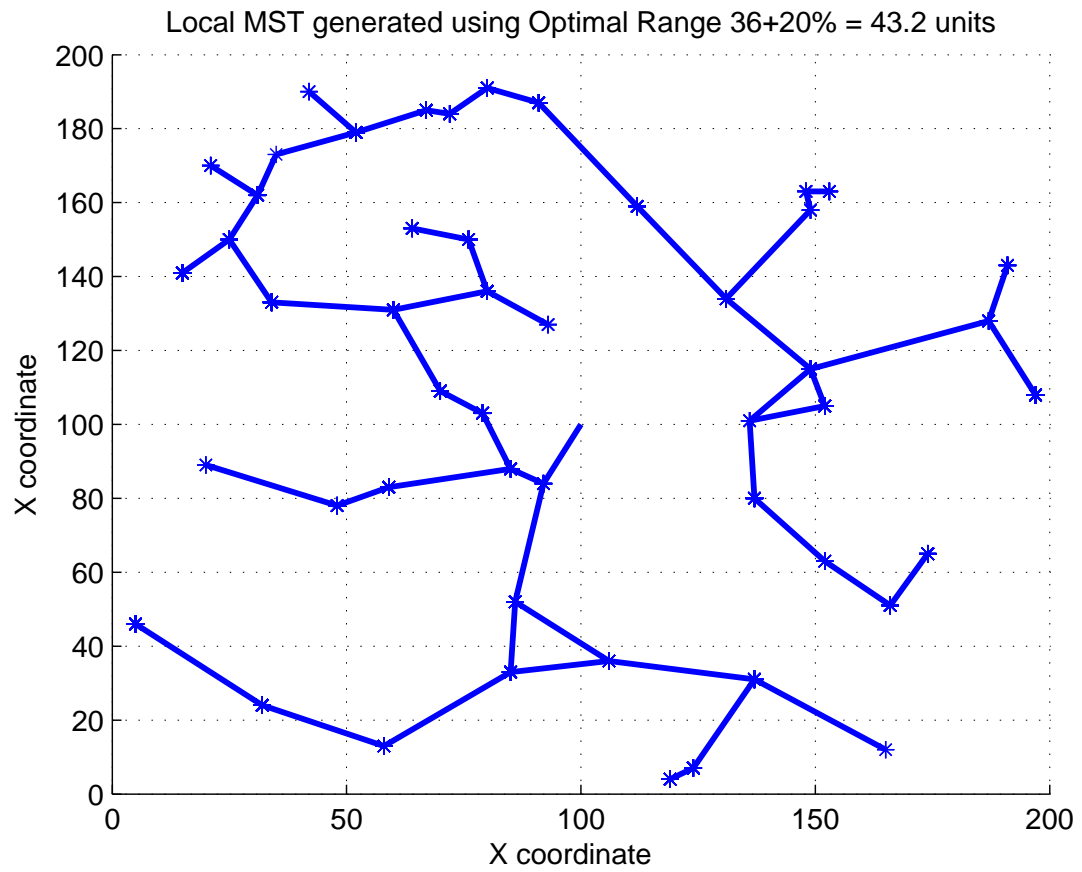


Figure 4.3: Local MST

Chapter 5

Modeling and Validation of LMST Algorithm using Colored Petri Nets

CPN and its Components

Implementation

Chapter Summery

Chapter 5

Modeling and Validation of LMST using Colored Petri Nets

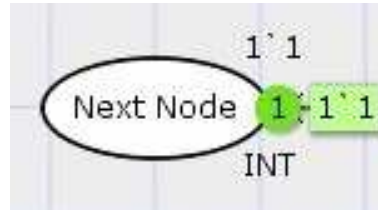
Modeling: is an artificial language which is used to describe systems or information in a structured way that is defined by a set of rules. Modeling is one way to reach the challenge of developing systems. It is an abstract representation which is supposed to be manipulated by a computer tool. It becomes possible to investigate the system behavior and the characteristics by using a model.

Validation: is the process of computing the degree upto which a modeling or simulation is accurate in representing the real world scenario. It ensures that the model meets its requirements in terms of the functions employed and the results obtained. The goal of validation is making the model useful in the perspective of solving the problem, and providing accurate information of the system being modeled. Validation makes the model actually used.

5.1 CPN and its Components

Colored petri nets are used for modeling and validation of systems. It provides synchronization, communication, and concurrency. Colored Petri Nets has three basic elements places, arcs and transition. We write inscriptions with the help of CPN ML programming language. Component of CPN [17]:

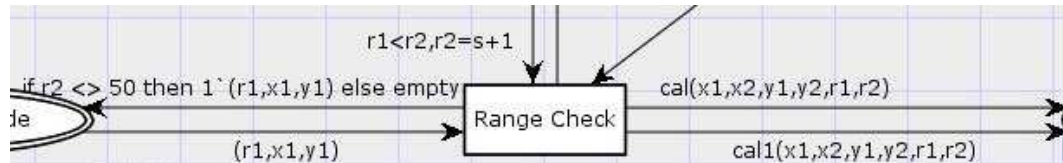
- Places: Places drawn as circles or ellipses. They contain token and each token is having a data value.



- Arc: Arcs can be bidirectional or unidirectional.



- Transition: Transitions drawn as rectangular boxes.



5.2 Implementation

Implementation in CPN-tools become easy and modular, when implemented hierarchically. So work is divided into four pages, one main page, two subpages and one sub-subpage.

Figure-5.1 shows the main page of CPN implementation. In which transition named 'Get-Nodes' takes all the random nodes generated from a text file named 'Out_new.txt' and transfer them to a place called 'All Nodes'. Then transition named 'Node Distributor' send one copy of nodes tokens to 'Main Set' and one copy to 'Copy Set'. There are two sub-pages also shown named 'Connection Enabler' and 'Range Check'.

Figure-5.2 shows first sub-page of the main page. In this sub-page node tokens are carried one by one from 'Main Set' to 'Main Set Next Node' to check with each node of 'Copy Set' one-by-one.

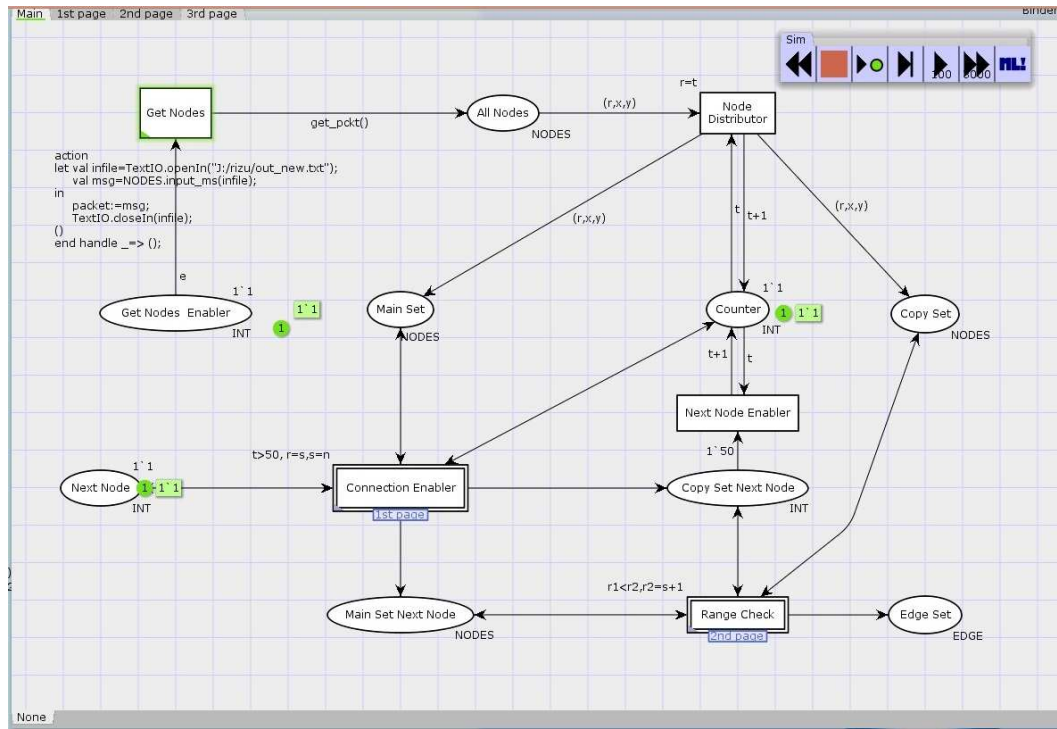


Figure 5.1: Main page of CPN validation

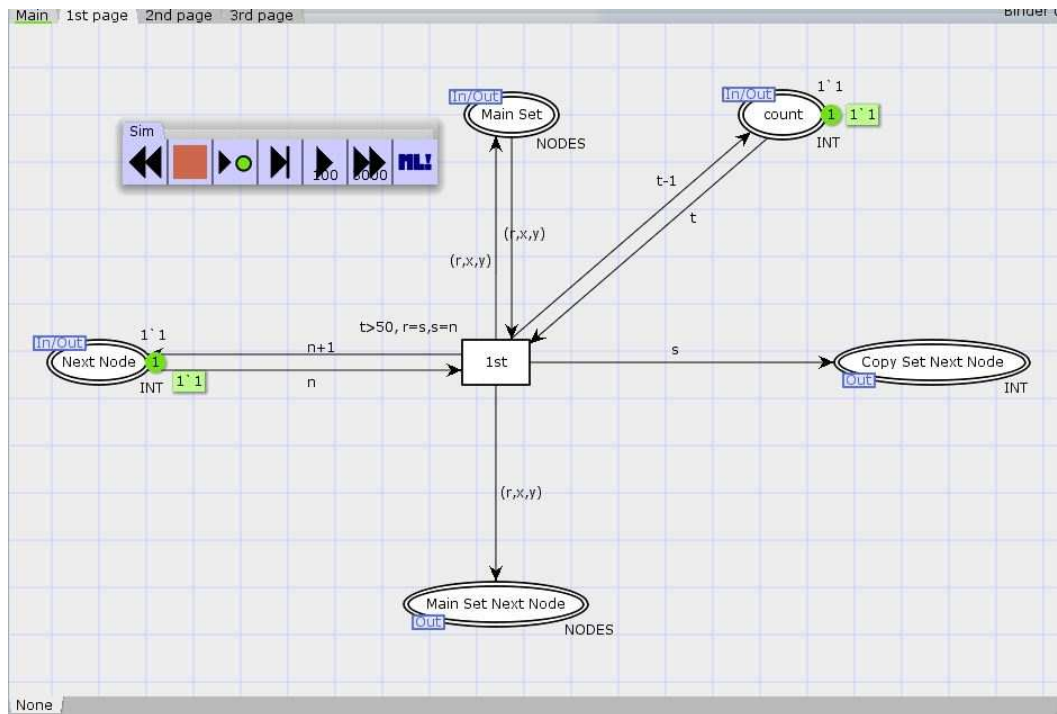


Figure 5.2: 1st sub-page of CPN validation

Figure-5.3 shows second sub-page of the main page. In this sub-page node tokens carried by '1st' from 'Main Set' are checked with each node of 'Copy Set' one-by-one with 'Range Check' transition. It generate and store the all possible edges into place named 'Edge Set'. All edges are computed with 'cal' function

$$funcal(x1, x2, y1, y2, r1, r2) = if(((x1 - x2) * (x1 - x2)) + ((y1 - y2) * (y1 - y2))) < 1866 then 1 * (r1, r2, ((x1 - x2) * (x1 - x2) + (y1 - y2) * (y1 - y2))) else empty$$

Then a sub-page of this sub-page is generated named as 'Local MST' which work on the 'Edge Set' to generate Local MST.

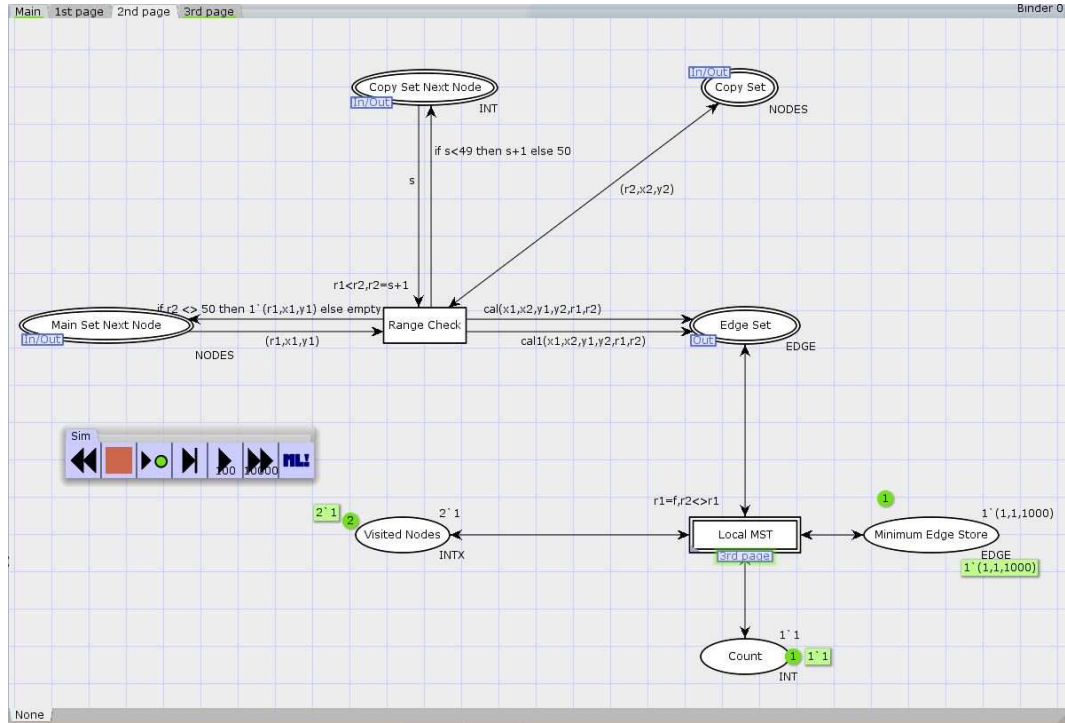
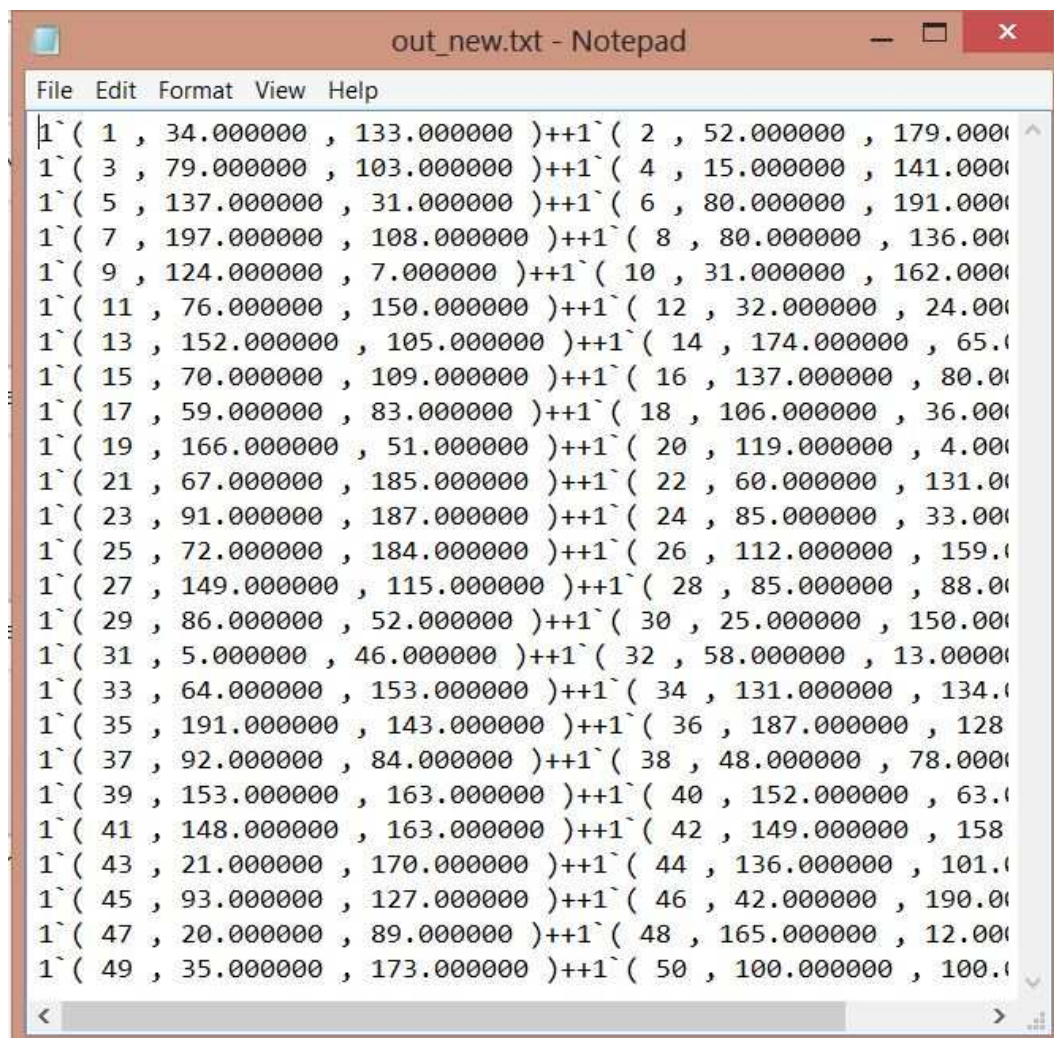


Figure 5.3: 2nd sub-page of CPN validation

figure-5.4 shows the only sub-subpage in the implementation, which is derived by the second sub-page of the main page. In this a 'Visited Node' place keeps the tokens of visited nodes, which enables 'Local MST' transaction to get a minimum edge from all visited nodes and transfers it to the 'Minimum Edge Store'. Then after a fixed count of minimum edge selection 'Minimum Edge Store' transfers it to the 'Minimum Edge Selector'. 'Minimum Edge Selector' decides whether the edge should be included in LMST or should be dumped by cycle formation check.

In Figure-5.5 the input file for CPN is shown, which is generated by the



```

1^ ( 1 , 34.000000 , 133.000000 )++1^ ( 2 , 52.000000 , 179.000000 )
1^ ( 3 , 79.000000 , 103.000000 )++1^ ( 4 , 15.000000 , 141.000000 )
1^ ( 5 , 137.000000 , 31.000000 )++1^ ( 6 , 80.000000 , 191.000000 )
1^ ( 7 , 197.000000 , 108.000000 )++1^ ( 8 , 80.000000 , 136.000000 )
1^ ( 9 , 124.000000 , 7.000000 )++1^ ( 10 , 31.000000 , 162.000000 )
1^ ( 11 , 76.000000 , 150.000000 )++1^ ( 12 , 32.000000 , 24.000000 )
1^ ( 13 , 152.000000 , 105.000000 )++1^ ( 14 , 174.000000 , 65.000000 )
1^ ( 15 , 70.000000 , 109.000000 )++1^ ( 16 , 137.000000 , 80.000000 )
1^ ( 17 , 59.000000 , 83.000000 )++1^ ( 18 , 106.000000 , 36.000000 )
1^ ( 19 , 166.000000 , 51.000000 )++1^ ( 20 , 119.000000 , 4.000000 )
1^ ( 21 , 67.000000 , 185.000000 )++1^ ( 22 , 60.000000 , 131.000000 )
1^ ( 23 , 91.000000 , 187.000000 )++1^ ( 24 , 85.000000 , 33.000000 )
1^ ( 25 , 72.000000 , 184.000000 )++1^ ( 26 , 112.000000 , 159.000000 )
1^ ( 27 , 149.000000 , 115.000000 )++1^ ( 28 , 85.000000 , 88.000000 )
1^ ( 29 , 86.000000 , 52.000000 )++1^ ( 30 , 25.000000 , 150.000000 )
1^ ( 31 , 5.000000 , 46.000000 )++1^ ( 32 , 58.000000 , 13.000000 )
1^ ( 33 , 64.000000 , 153.000000 )++1^ ( 34 , 131.000000 , 134.000000 )
1^ ( 35 , 191.000000 , 143.000000 )++1^ ( 36 , 187.000000 , 128.000000 )
1^ ( 37 , 92.000000 , 84.000000 )++1^ ( 38 , 48.000000 , 78.000000 )
1^ ( 39 , 153.000000 , 163.000000 )++1^ ( 40 , 152.000000 , 63.000000 )
1^ ( 41 , 148.000000 , 163.000000 )++1^ ( 42 , 149.000000 , 158.000000 )
1^ ( 43 , 21.000000 , 170.000000 )++1^ ( 44 , 136.000000 , 101.000000 )
1^ ( 45 , 93.000000 , 127.000000 )++1^ ( 46 , 42.000000 , 190.000000 )
1^ ( 47 , 20.000000 , 89.000000 )++1^ ( 48 , 165.000000 , 12.000000 )
1^ ( 49 , 35.000000 , 173.000000 )++1^ ( 50 , 100.000000 , 100.000000 )

```

Figure 5.5: Text file from MATLAB for the input to CPN

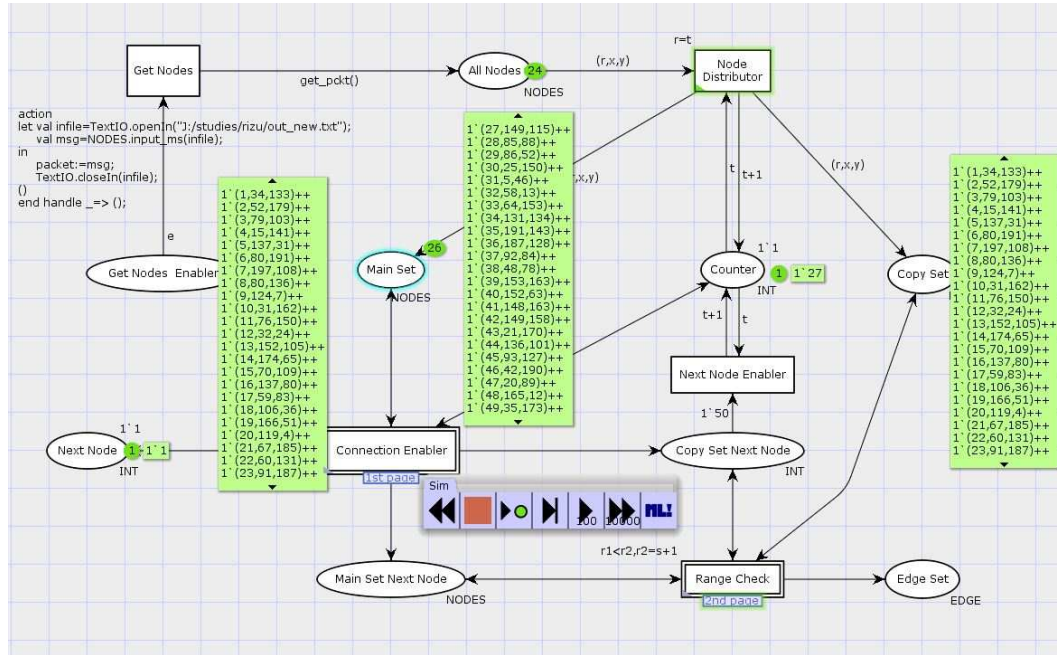


Figure 5.6: Node distribution in Main Page of CPN

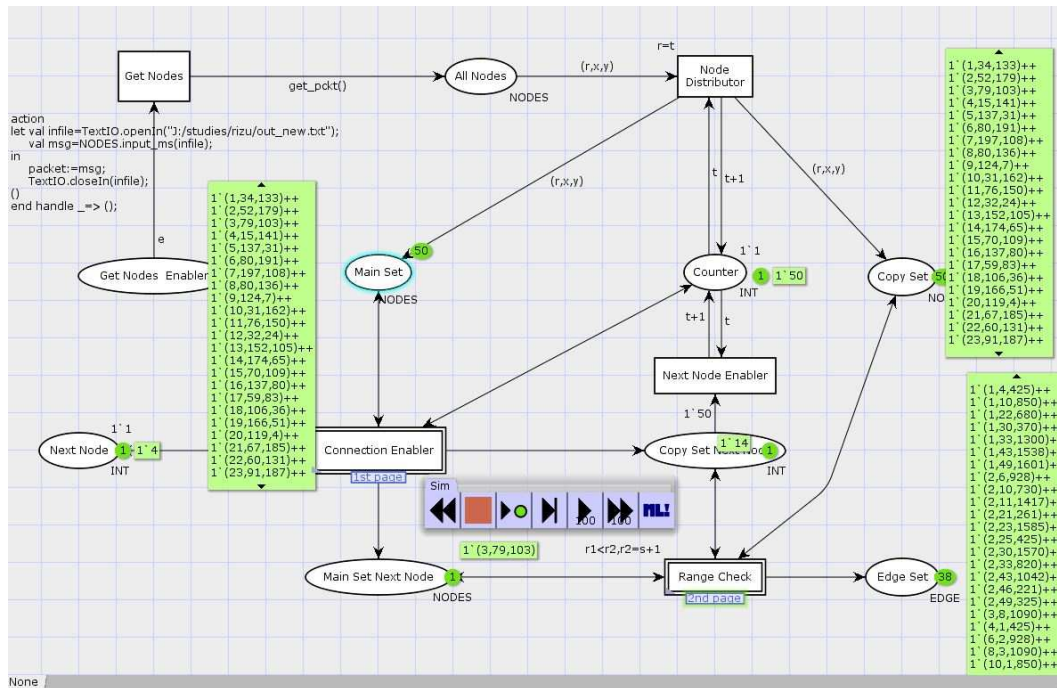


Figure 5.7: Possible Edge Generation

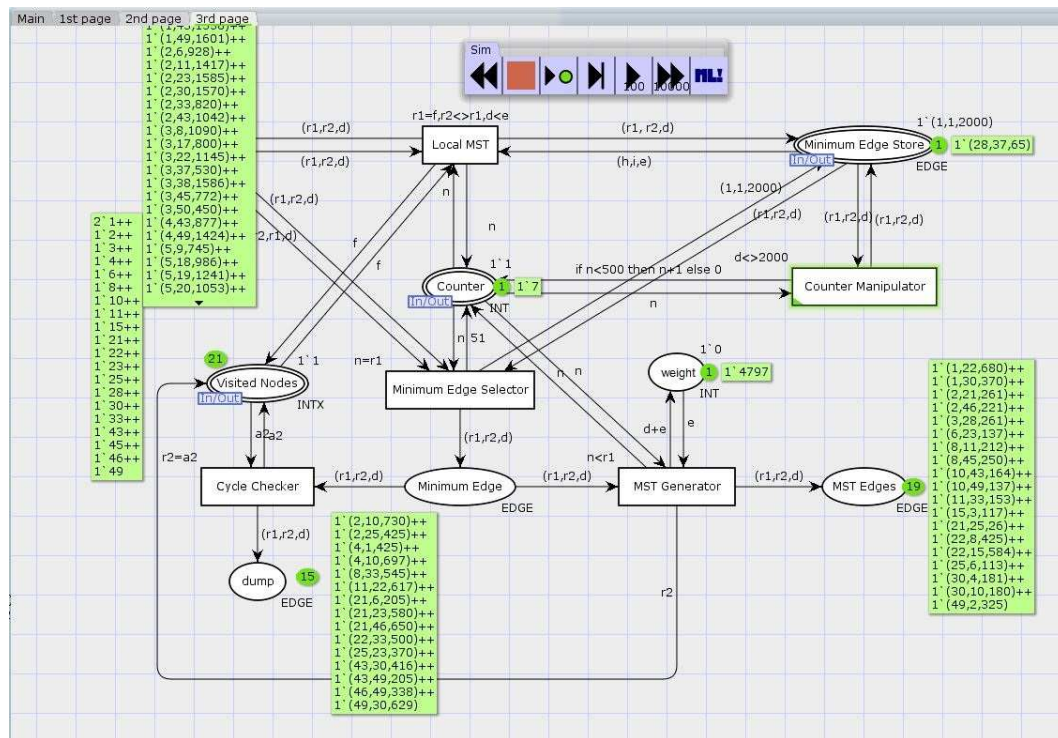


Figure-5.11 shows complete LMST with 49 edges, which is 1 less than the number of nodes, which is 50. The ‘weight’ place contains the total edge weight of the LMST. As the LMST now contains 49 edges, so all the remaining edges must go to the ‘dump’ place.

As we can see in Figure-5.13 that, the value of weight (w) computed by MATLAB is 22993, which is exactly same as the weight value computed by CPN. And the LMST generated by MATLAB in Figure-5.12 contains similar edges to the LMST generated by CPN in Figure-5.14.

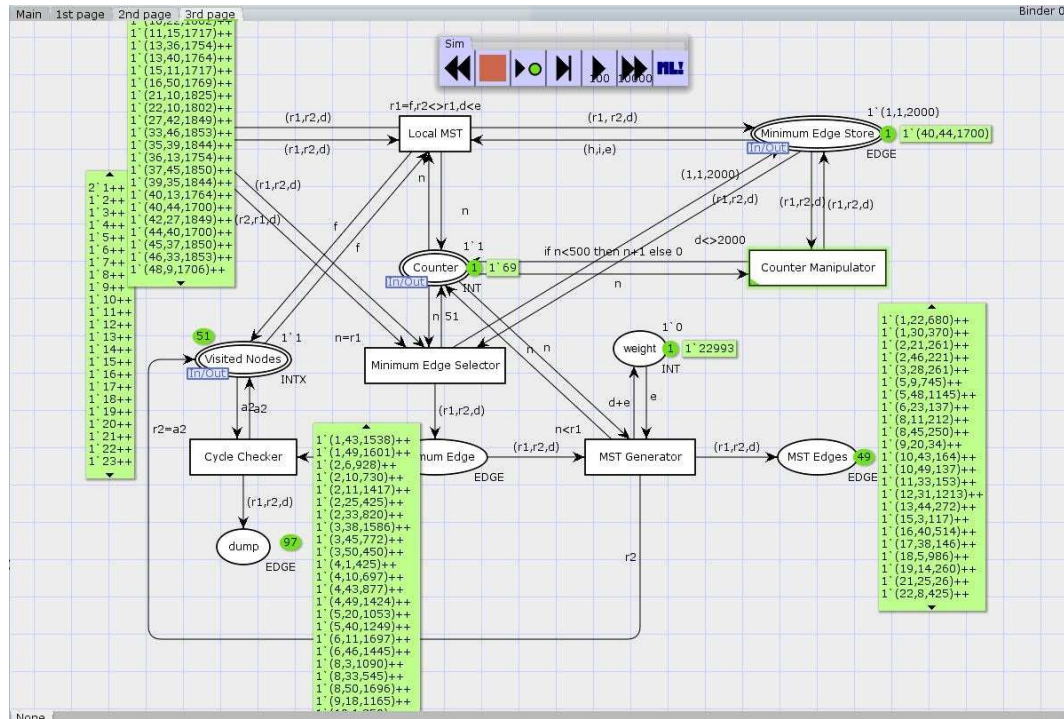


Figure 5.11: Complete LMST with edges to be dumped

5.3 Chapter Summery

In this chapter the LMST algorithm simulated in MATLAB is modeled and validated by CPN. The results are compared with each other, and found matched.

T <49x3 double>					
	1	2	3	4	5
1	1	30	370		
2	1	22	680		
3	2	46	221		
4	2	21	261		
5	2	49	325		
6	3	15	117		
7	3	28	261		
8	4	30	181		
9	5	9	745		
10	5	18	986		
11	5	48	1145		
12	6	25	113		
13	6	23	137		
14	7	36	500		
15	8	11	212		
16	8	45	250		
17	8	22	425		
18	9	20	34		
19	10	49	137		
20	10	43	164		
21	10	30	180		
22	11	33	153		
23	12	32	797		
24	12	31	1213		
25	13	27	109		
26	13	44	272		

Figure 5.12: LMST Edge Set with lengths

Name ▲	Value	Min	Max
T	<49x3 double>	1	1613
a	<50x2 double>	4	197
connection	<158x3 double>	1	1853
fid	12	12	12
i	49	49	49
j	50	50	50
k	[]		
lines	159	159	159
m	49	49	49
max	200	200	200
n	50	50	50
nodes	<50x1 double>	25	1613
range	43.2000	43.2...	43.2...
temp	9554	9554	9554
w	22993	22993	22993

Figure 5.13: Work-space of MATLAB work

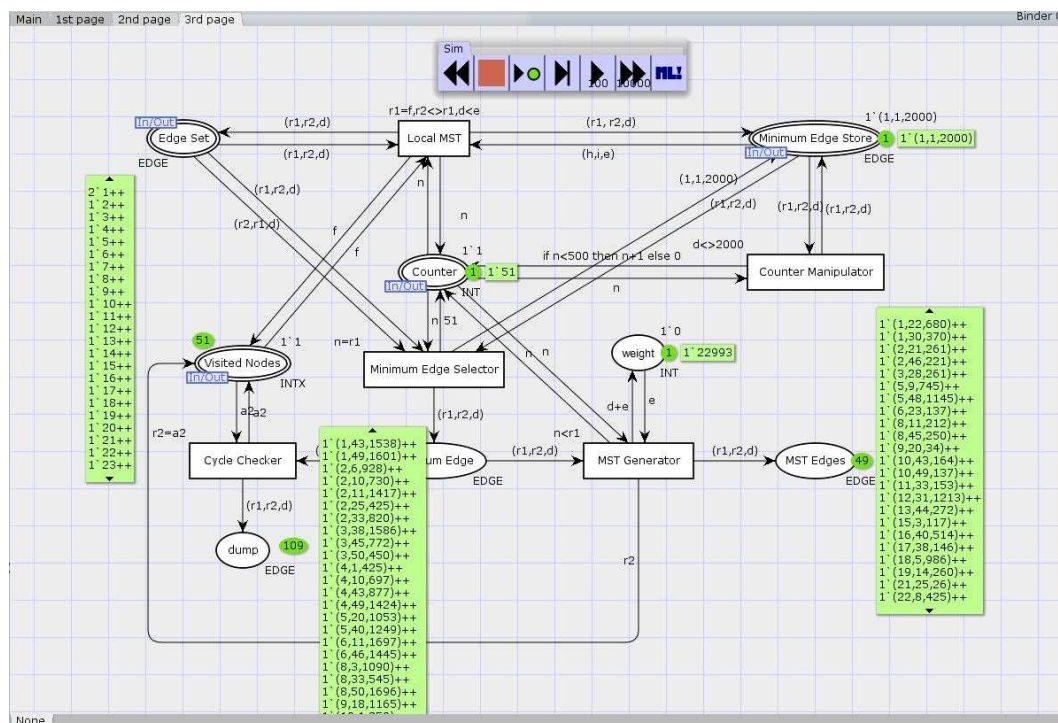


Figure 5.14: Complete LMST with no edges to be dumped

Chapter 6

Conclusion and Scope of Future Work

Chapter 6

Conclusion and Scope of Future Work

CPN can be used to modeling and validation of a real-time system in which correctness depends on the timing of data tokens. This work helps in understanding properly the impact of LMST on the performance of broadcasting in WSN, and provide the modeling and validation. It is better to use the localized network algorithm than global, because it is less time consuming. So to have energy efficient broadcasting a LMST algorithm using the Optimal Transmission Range has been proposed and validated. The work is validated by the CPN tools to verify the nodes connections (Edges) and LMST when the Optimal Transmission Range is taken into account.

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